

# *Siamusotima aranea*, a New Stem-Boring Musotimine (Lepidoptera: Crambidae) from Thailand Feeding on *Lygodium flexuosum* (Schizaeaceae)

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**ABSTRACT** *Siamusotima aranea* Solis & Yen, is a new stem-boring musotimine species from Thailand. It was discovered in the stems of *Lygodium flexuosum* (L.) Sw. (Schizaeaceae) during exploration for biological control agents of *Lygodium microphyllum* (Cav.) R. Br., the Old World climbing fern. This is the first report in the Pyraloidea of a stem-boring larva with unique modifications of the anal segment resembling that of tenebrionid beetle immatures and with observations of possible mimicry between the adult moth and spiders.

**KEY WORDS** Pyraloidea, Old World climbing fern, pteridophagy, spiders, tenebrionid beetles

EXPLORATION FOR BIOLOGICAL control agents of *Lygodium microphyllum* (L.) Sw., the Old World climbing fern, has been conducted in Australia and southeastern Asia since 1998 by the Agricultural Research Service–Australian Biological Control Laboratory in Brisbane, Queensland (Goolsby et al. 2003a, b). This fern is an invasive weed in southern Florida where it threatens many wetland communities, including the Everglades (Pemberton and Ferrier 1998; Pemberton et al. 2002; Goolsby et al. 2003a, b). Among the insect species discovered on *Lygodium* species and proposed for use as biological control agents, those of the Musotiminae (Crambidae) are especially significant because a number of species in different genera have been found to exclusively consume *Lygodium*. Musotimines discovered previously were external fern feeders (Goolsby et al. 2003a, b; Solis et al. 2004; Yen et al. 2004), but recently one species was found boring into the stems of *L. flexuosum* in Thailand. We describe all life stages of this new genus and species, and discuss the placement of the genus. We also discuss the pos-

sible mimicry of the adult wing pattern to Thomisidae spiders and the resemblance of the anal segment of the lepidopteran larva to anal segment of tenebrionid immatures.

## Materials and Methods

**Biological Exploration Methods.** The following countries were visited between September 1998 and March 2002: Australia, China, Japan, Indonesia, Malaysia, New Caledonia, Singapore, Taiwan, and Thailand. Specific search areas were selected by climate matching, habitat similarity, herbarium locality data, and information provided by knowledgeable specialists. Methods for collection included hand searches, sweeping, beating of foliage, and dissection of underground plant parts (Goolsby et al. 2003a).

**Taxa Studied.** Specimens were studied from The Natural History Museum, London, United Kingdom (BMNH). Type material is deposited in those institutions as designated within the text. To determine the identity and/or placement of the taxa feeding on *Lygodium*, the type species, and other species if available, of all described genera currently in the Musotiminae, including several newly published and unpublished genera by Solis et al. (2004), Yen et al. (2004), and S.-H.Y. (unpublished data), were dissected, studied, and compared. The diagnosis below is composed of synapomorphies.

Pinned specimens were examined and dissected after abdomens were soaked in 10% potassium hydroxide and wings were soaked in bleach. Dissections were stained in chlorazol black for genitalia, and Eosin-Y for wings. Genitalia were placed in vials with

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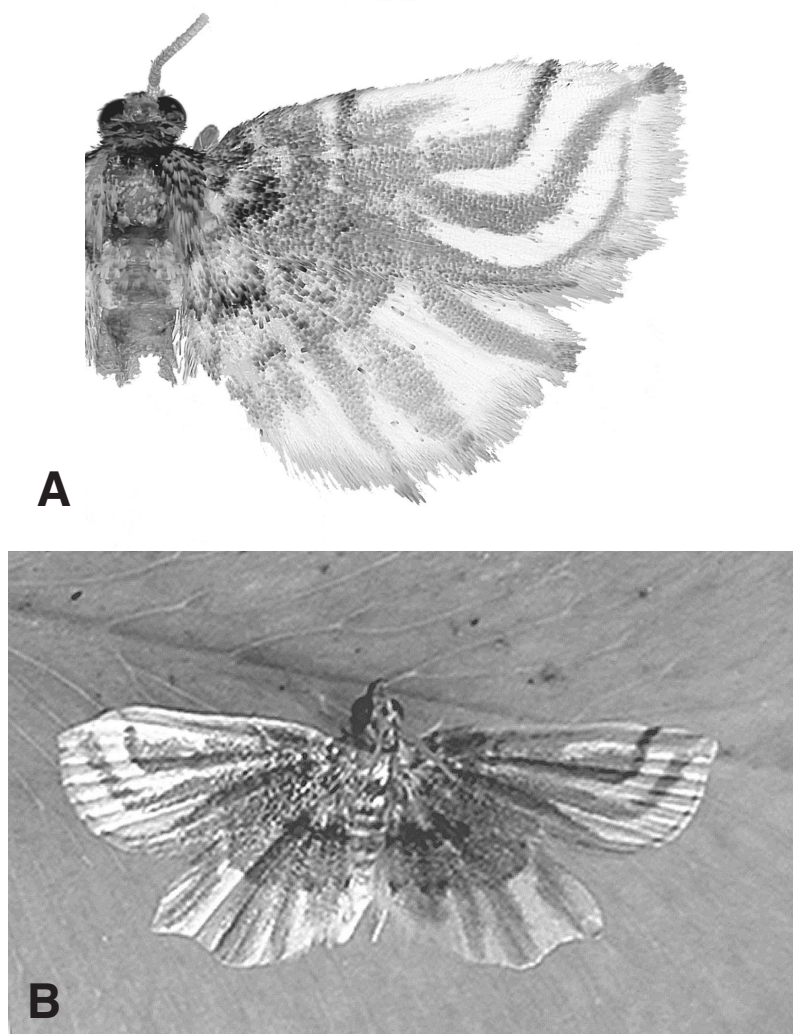


Fig. 1. (A) Male adult of *S. aranea*, Thailand, Chiang Mai, Ban Pong, Mae Jo. (B) Live adult of *S. aranea*, Australian Biological Control Laboratory.

glycerin and/or slide mounted in Canada balsam or Euparal (Clarke 1941, Holloway et al. 1987). Measurements were made with an ocular micrometer. Forewing length was measured from the center of the axillar area to the apex of the forewing. Terminology follows Hinton (1946), Klots (1970), Maes (1985, 1995, 1997), Yoshiyasu (1985), Phillips and Solis (1996), Munroe and Solis (1999), and Solis and Maes (2002).

## Results and Discussion

### *Siamusotima* Solis & Yen, New Genus (Figs. 1A and B, 2A, 4A–C)

**Diagnosis.** Forewing with three brown bands curving anteriorly to apex and hindwing with four longitudinal lines radiating from median line to outer margin on an otherwise white ground color; uncus base as

broad as vinculum; valva with sclerotized lobe directly over saccular lobe pointing anteriorly; sacculus medially with a small membranous saccular lobe pointing posteriorly. Larva elongate with abdominal prolegs and crochets reduced, and the caudal segment a sclerotized cup-like structure.

**Etymology.** The prefix of the generic epithet is derived from the Latin “*siam*” referring to the historical name of Thailand where this taxon was first discovered, and the generic stem “*musotima*” referring to its relationship to this genus in the subfamily. The gender of the genus is feminine.

**Type Species.** *Siamusotima aranea* Solis & Yen

**Comparison and Phylogenetic Relationships of *Siamusotima* to Other Genera in the Musotiminae.** *Siamusotima* has strikingly distinct larval morphology from all other musotimine genera. Compared with the larva of “*Cataclysta*” *angulata* Moore, a leaf miner on

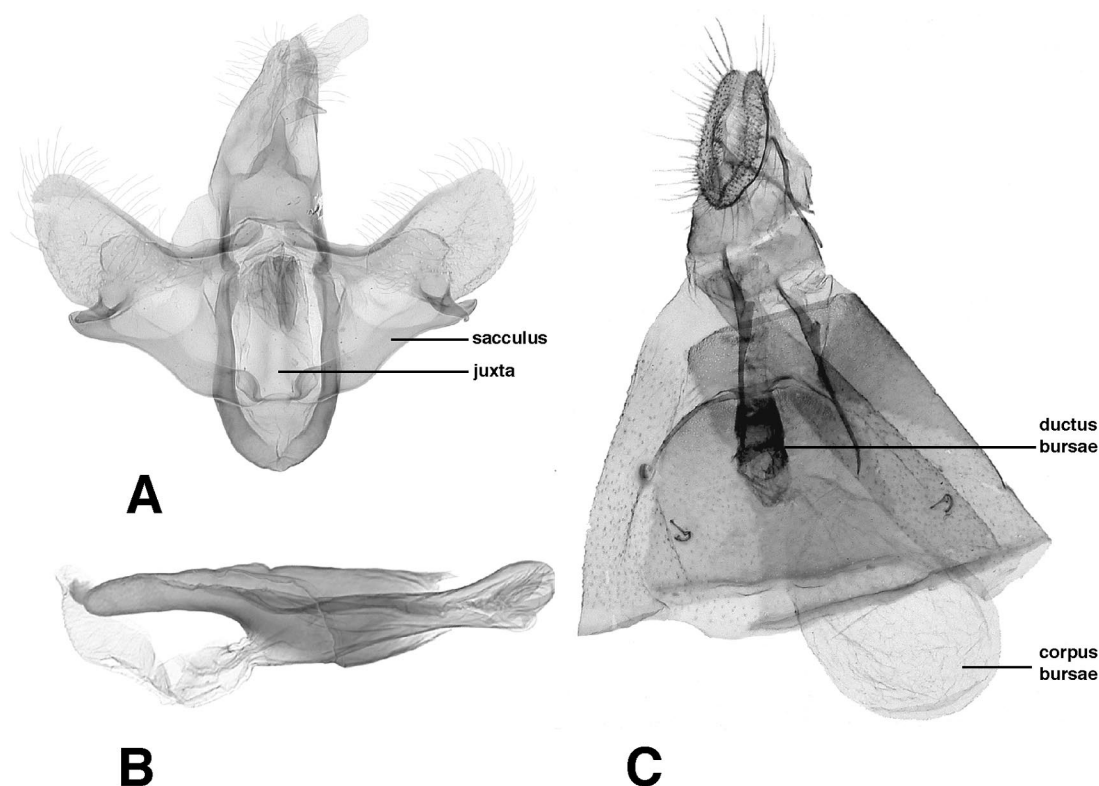


Fig. 2. (A) Male genitalia of *S. aranea*. (B) Male aedoeagus of *S. aranea*. (C) Female genitalia and caudal segments of *S. aranea*.

*Nephrolepis cordifolia* (L.) Presl. (Oleandraceae) (Yen et al. 2004), the larva of *Siamusotima* is more highly adapted to an endophagous environment with its elongated body, reduced prolegs and crochets of A3-A6, and a cup-like caudal abdominal segment. Although both larvae are internal feeders, we do not consider that they are closely related because the pupal shape, genitalic characters, and host association of "*Cataclysta*" *angulata* reveal its phylogenetic affinity with *Eugauria* Snellen. The pupal shape of *Siamusotima* is similar to that of *Musotima dryopterisivora* Yoshiyasu (as *Musotima accleralis* Walker in Nakamura 1977) and *Neurophyseta* Hampson (S.-H.Y., personal observation), but the latter have reduced frontoclypeal setae. The pupal shape of these three genera is also similar to those of *Lygomusotima* Solis & Yen, *Neomusotima* Yoshiyasu, and *Austromusotima* Yen & Solis, but the latter three genera lack the protruded conical spiracles.

In the adult, the forewing of *Siamusotima* is basally brown and distally white with three brown bands curving anteriorly to the apex. In *Lygomusotima*, another genus that occurs in Thailand, the entire wing is light brown except the area between the postmedial and subterminal line that is distinctively patterned with a bright, white triangle that spans  $R_5$  and  $M_1$ . The entire uncus of *Siamusotima* is broad, and in *Lygomusotima* the apex is about half as wide as the base.

*Lygomusotima* has a simple valva without lobes, with a slightly indented sacculus, but in *Siamusotima* the valva has a sclerotized lobe directly over the saccular lobe pointing anteriorly and the sacculus has a medial, small membranous saccular lobe pointing posteriorly. Both *Lygomusotima* and *Siamusotima* have a basally quadrate, bifurcate juxta, but in *Siamusotima* the juxta is only three-quarters as long as the vinculum with indistinct juxtal arms and in *Lygomusotima* the juxta is as long as the vinculum with distinct juxtal arms. The female genitalia of *Siamusotima*, has a membranous corpus bursae without a signum and the ductus bursae is slightly constricted with an internal circle of sclerotized, minute, teeth. The corpus bursae of *Lygomusotima* is rugose with a signum.

The male genitalia of *Siamusotima* is similar to those of *Ambia ptolycusalis* Walker, *Musotima aduncalis* Felder & Rogenhofer, *Neurophyseta*, *Melanochroa* Yoshiyasu, *Undulambia* Lange, and *Uthinia* Snellen in having a ventral valval process. However, the valval process of *Siamusotima* is more robust and cornate. Also, the broad uncus of *Siamusotima* indicates that this new genus is not closely related to those genera that have a slender uncus, e.g., *Aeolopetra* Meyrick, *Cilaus* Joannis, *Cymoriza* Guenée, *Drosophantis* Meyrick, and *Parthenodes* Guenée. *Siamusotima* may be most closely related to *Musotima* because both genera have a medial ventral valval process and very similar

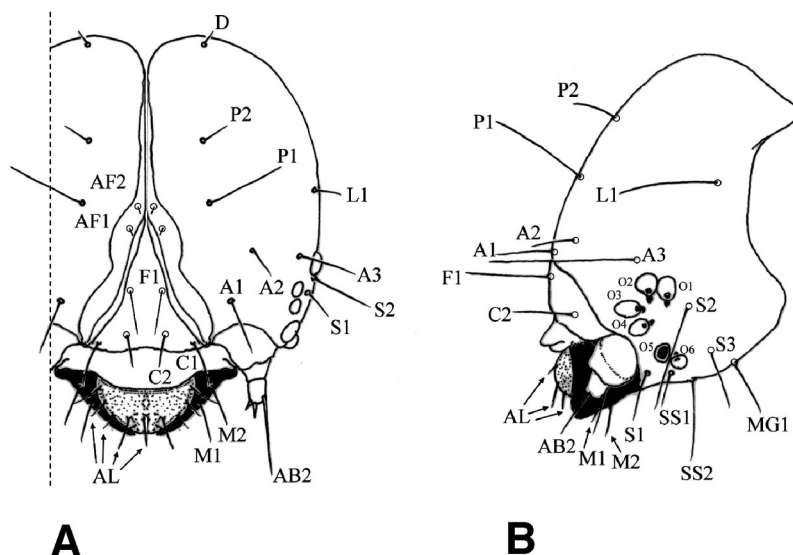


Fig. 3. (A) Frontal view of cranial chaetotaxy of *S. aranea*. (B) Lateral view of cranial chaetotaxy of *S. aranea*. A, anterior setae; Aa, pore near seta A2; S, stemmatal setae; SS, submental setae; F, frontal setae; AF, adfrontal setae; C, clypeal setae; L, lateral setae; La, pore near L1; P, posteriodorsal setae; MG, genal setae; M, mandibular setae; AL, labral setae.

pupal shape, but *Siamusotima* is still distinguished from *Musotima* by having much narrower valva, broader uncus, and internally feeding larvae.

### Challenges in the Definition and Placement of Musotimine Genera

Because the classification of Hampson (1897) classification of the Hydrocampinae based on adults, the majority of musotimine species have been placed in two large and systematically chaotic genera, *Ambia* Walker (type species *Ambia ptyolycusalis* Walker) and *Musotima* Meyrick (type species *Diathrausta aduncalis* Felder & Rogenhofer). All other musotimine genera, except for the Neotropical *Neurophyseta* (Munroe et al. 1995, Phillips and Solis 1996), are either monotypic or comprise two to 10 species. However, it is still difficult to determine whether we can apply these two generic names to at least 100 musotimine species other than their type-species groups. The morphology of *A. ptyolycusalis* is very "simple" and "conservative," and similar character states also can be seen in some species presently placed in *Musotima*. With very little information, we are unable to determine whether these two genera are monophyletic, closely related, congeneric, or applicable to some undescribed species-groups. In this article and other studies of musotimine systematics, we have avoided creating new genera that would lead existing genera, such as *Ambia* and *Musotima*, to be para- or polyphyletic, and we have recognized all other existing genera that demonstrate clear morphological gaps from the *A. ptyolycusalis* and the *M. aduncalis* species-groups based on both adults and immatures. Yen et al. (2004) illustrated that there is low phylogenetic correlation between adult and immature morphology of Musotimi-

nae. Thus, using only adult or immature characters may not successfully justify generic status and phylogenetic affinity of a musotimine species.

### *Siamusotima aranea* Solis & Yen

(Figs. 1A and B, 2A–C, 3A and B, 4A–F, 5A–F, 6A–C)

**Adult. Head** (Fig. 1A and B). Frons brown, white laterally, and vertex brown; antennae white, prismatic, laterally compressed; labial palpi three-segmented, white medially, brown laterally, second segment with a fan of scales; maxillary palpi white medially, brown laterally. Proboscis scaled white basally. Chaetosemata and ocelli absent.

**Thorax** (Fig. 1A and B). Thorax, patagium, and tegulae white, with dark brown-tipped scales. Legs white, tibiae brown laterally.

**Forewing** (Fig. 1A and B). Average forewing length 6.0 mm ( $n = 7$ ). Costal swelling absent. Costa brown to apex or white from basal area to apex. Margin incised or slightly crenulate with brown scales as a continuous line from the apex along the outer margin around the anal angle and along posterior margin to base of 1A+2A. Vein  $R_1$  and  $R_2$  from discal cell,  $R_3$  and  $R_4$  stalked near apex of wing, arising from apex of discal cell,  $R_5$  close at base;  $M_1$  straight;  $M_2$  connected to  $M_3$  by perpendicular vein at base just beyond where  $M_3$  and  $CuA_1$  are more or less approximate at base; 1A+2A strongly sclerotized. Basal area dark brown, light brown distally. Median line dark brown. Two brown bands extending distally from median line on white wing, one along the length of Cu and  $CuA_2$  curving anteriorly to apex of wing extending to fringe, one a dark brown line along  $M_1$  curving anteriorly to



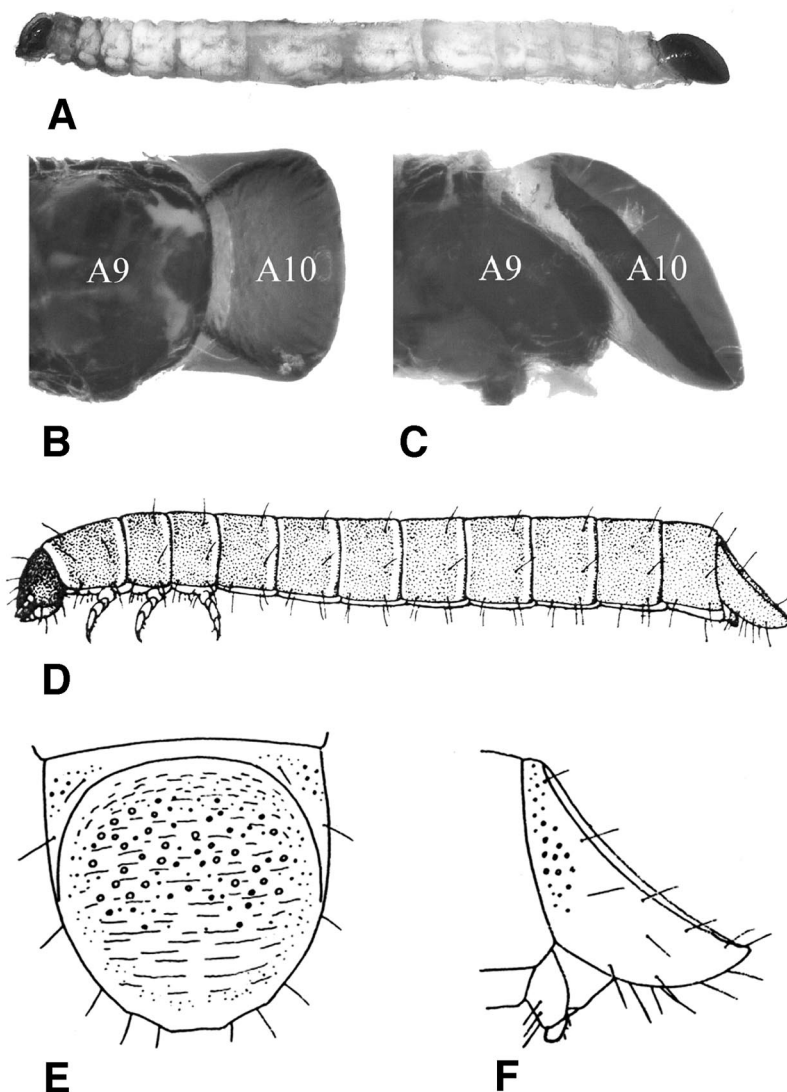


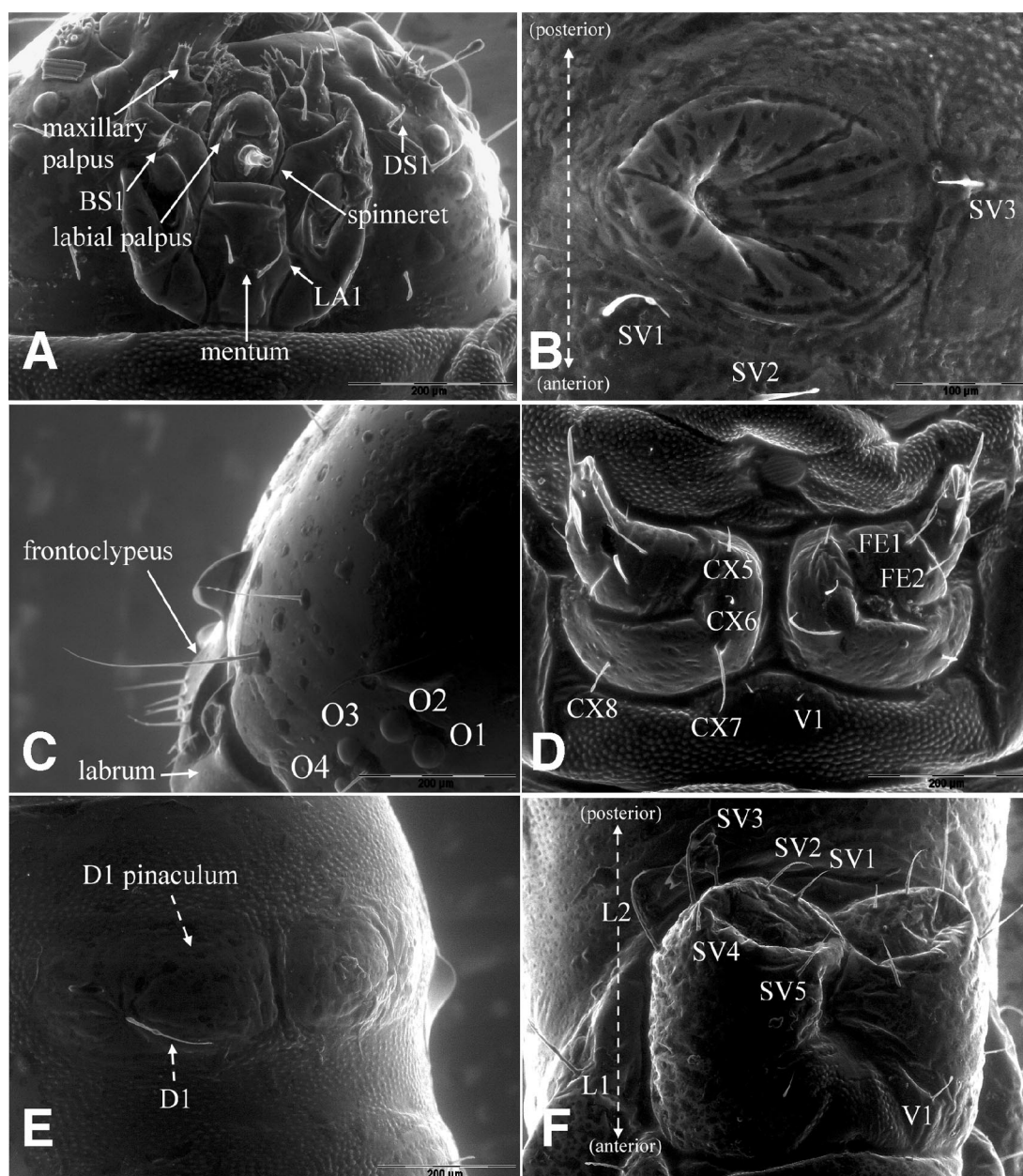
Fig. 4. Last instar of *S. aranea*. (A) Lateral view *S. aranea*. (B) Ventral view of cup-like structure of *S. aranea*. (C) Lateral view of cup-like structure of *S. aranea*. (D) Lateral view of tenebrionid immature, *P. nigrocyaneus* Motschulsky, from Hayashi (1966). (E) Dorsal view of cup-like structure of *P. nigrocyaneus* from Hayashi (1966). (F) Lateral view of cup-like structure *P. nigrocyaneus* from Hayashi (1966). A, abdominal segments.

costa. Short brown band from median line along R vein to half the length of wing. Fringe white. Underside white with dark brown bands highly visible; color and pattern as on upperside of wing. Male retinaculum a short set of setae pointing toward costa located basally on Cu.

**Hindwing** (Fig. 1A and B). Costa straight; apex rounded; termen slightly sinuous to tornus. Veins Sc and R separate at base, vein Sc+R<sub>1</sub> then anastomosed with Rs for short distance, M<sub>1</sub> straight with a perpendicular line toward M<sub>2</sub>; M<sub>2</sub> to CuA<sub>1</sub> as in forewing; CuA<sub>2</sub>, 1A+2A, and 3A complete. Margin crenulate. Basal area dark brown, light brown distally. Median

line dark brown. Four longitudinal lines radiating from median line to outer margin along Rs, M<sub>2</sub>, CuA<sub>2</sub>, and 1A+2A. Underside white with dark brown basal area and longitudinal bands highly visible. Male frenulum with one seta, female with three setae.

**Abdomen.** Tergites one and two white with some brown-tipped scales, tergites 3 and 4 completely brown, remaining tergites white. Tympanal organs: Tympanal cases (=bulla tympani, caisses tympaniques) reduced, tympanal frame (=fornix tympani, cadre tympanique) highly sclerotized, processes tympani (=sailles tympaniques) absent, ramus tympani absent.



**Fig. 5.** (A) SEM of ventral view of cranial setae and structures of *S. aranea*. (B) Scanning electron micrograph (SEM) of reduced proleg of A3 of *S. aranea*. (C) SEM of lateral view of cranial setae of *S. aranea*. (D) SEM of ventral view of metathoracic legs and the associated setae of *S. aranea*. (E) SEM of dorsal view of A3 of *S. aranea*. (F) SEM of ventral view of caudal prolegs of *S. aranea*. BS, basistipes setae; DS, dististipes setae; LA, labio-hypopharyngeal setae; D, dorsal setae; L, lateral setae; SV, subventral setae; V, ventral setae; CX, coxal setae; FE, femoral setae.

**Male genitalia** (Fig. 2A and B). Uncus basally as broad as vinculum, slightly tapering to a membranous round apex; gnathos (=pseudognathos of Maes 1997, Solis and Maes 2002) mostly membranous with sclerotized spinules dorsally, arms tapered to tegumen; tegumen continuous, forming an inverted "U" with ventral sclerotized extension to costa of valva; juxta bifurcated, three-quarters as long as vinculum, basally

quadrate; transtilla medially membranous; valva simple, apical margin rounded, sclerotized lobe directly over saccular lobe pointing anteriorly; basally sacculus overlaps juxta, sacculus medially with a small membranous saccular lobe pointing posteriorly; vinculum broadly sclerotized, two times as long as tegumen. Aedoeagus simple without cornuti, distal half lightly sclerotized; coecum one-third length of aedoeagus.

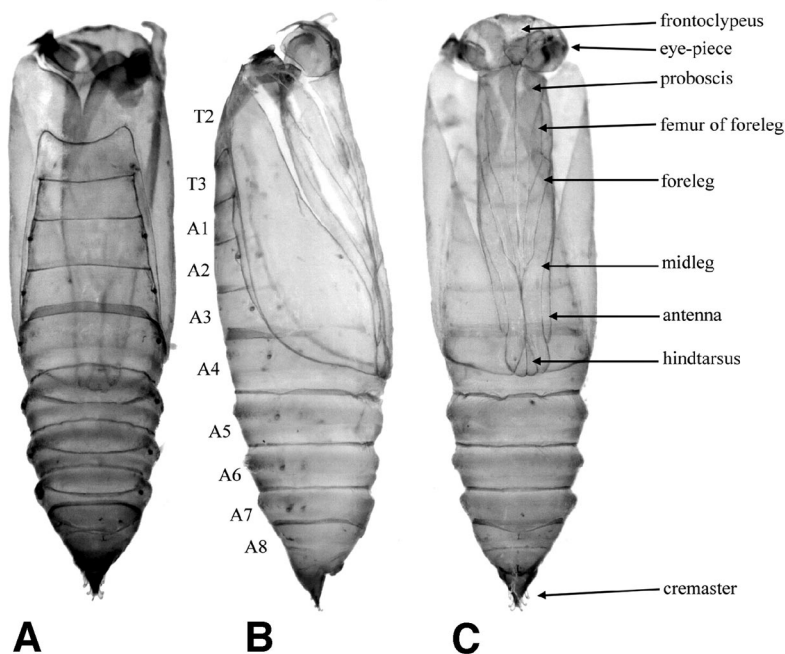


Fig. 6. Pupal cases of *S. aranea*. (A) Dorsal view. (B) Lateral view. (C) Ventral view. T, thoracic segments; A, abdominal segments.

**Female Genitalia** (Fig. 2C). Corpus bursae membranous, as long as seventh segment; signum absent; appendix bursae absent; ductus seminalis originating from ventroposterior area of corpus bursae; ductus bursae membranous posteriorly, slightly sclerotized from ostium bursae to half the length of ductus where it is slightly constricted with an internal circle of minute sclerotized teeth; posterior apophyses two-thirds as long as anterior apophyses; papillae analis anteroposteriorly flattened, indented mediodorsally.

**Larva** (Figs. 3A and B, 4A–C, and 5A–F). Head hypognathous, epicranial suture very short; height of frontoclypeus 1.15 times width; six stemmata, C1 and C2 approximate, C3 and C4 approximate, C5 antero-ventrad to C6; S2 longer than S1, SS2 longer than SS1, MG1 as long as S3, F1 present near middle of frontoclypeus, AF1 and AF2 on adfrontal area extremely short, La and Aa absent, D short, P2 shorter than P1; labrum with five short setae on each side externally; mandible with one row of serrations, M1 as long as M2. T1–3 and A1–10 integument smooth, segments without chalazae, pinacula only very weakly present dorsally. Prothoracic shield weakly sclerotized, D1 shorter than D2, XD1 shorter than XD2, SD1 and SD2 absent, L and SV setae absent. T2–T3 with D setae bisetose; SD setae bisetose; L setae unisetose; SV present, as long as L setae; V setae very short. A1–A2 with D setae bisetose; SD group bisetose, SD1 as long as L2 of T2–3; L, SV and V groups unisetose. Setal map of A3–8 in general similar to A1–2. A9 with D, SD, L, SV and V groups unisetose, and with spiracle switched to posterodorsal part. A10 with anal shield modified as a cup-like structure with margin surrounded by D, SD,

PP and L group setae; L1 situated in front of cup-like structure. Thoracic legs present, with developed CX and FE setal groups. Prolegs of A3–A6 reduced and crochets of A3–A5 absent; crochets of A6 weakly present as semicircular and uniserial form. Caudal prolegs of A10 extending posteriorly and situated beneath cup-like structure, crochets absent.

**Pupa** (Fig. 6A–C). Ventral view: Frontoclypeus of head slightly concave; labrum narrow; maxillary palpus visible near base of proboscis case; proboscis extending to middle of A2; fore-femur visible, prothoracic legs (foreleg) two-thirds length of forewing case, reaching to end of A2; mesothoracic leg (midleg) extending to middle of A4, longer than antennal sheath; hindtarsus visible; abdominal segments 5–6 without vestigial prolegs; abdominal segments 8–10 with genital orifice anteriorly; anus posteriorly without lateral conical depressions. Dorsal view: prothorax smooth, with two very short dorsolateral horn-like structures; mesothorax without setae; surface of abdominal tergites and wing sheath smooth; cremaster somewhat flattened dorsoventrally with a truncate apex and three pairs of curved setae.

**Type Material.** HOLOTYPE: Male, Thailand, Chiang Mai, Ban Pong, Mae Jo, May 2003, A. Winotai, Ex: *Lygodium flexuosum*. Deposited at the Raffles Museum of Biodiversity Research, National University of Singapore, Singapore (NUS).

**PARATYPES.** Two males, Thailand, Chiang Mai, Ban Pong, Mae Jo, May 2003, A. Winotai, Ex: *Lygodium flexuosum*; one male, Thailand, Ban Pong, Mae Jo, Chiang Mai, N 18° 55.61 E 99° 33.01, 15-VI-2001, A. Winotai, *Lygodium* stem borer; three females, Thai-



land, Chiang Mai, Ban Pong, Mae Jo, May 2003, A. Winotai, Ex: *Lygodium flexuosum*. Paratypes deposited at The National Museum of Natural History, Smithsonian Institution, Washington, DC.

#### Distribution. Thailand.

**Etymology.** The specific name is derived from the Latin *aranea* and denotes the resemblance of the adult moth wing pattern to a spider.

**Biology.** A comprehensive description of laboratory and field rearings of this species can be found in Goolsby et al. (2003a) from which the following is taken. Eggs are laid on the upper surface of the leaf and remain in this stage 7–10 d. Newly eclosed larvae move to the tip of the stem, and then they move and tunnel downwards through the stem, periodically making holes through which frass can be seen outside the stem; up to 15 larvae have been found in a single stem. Pupation occurs on the outside of the stem. Adults are attracted to light from late April to June, and it seems that there are two generations per year in Thailand. *L. flexuosum* is found in upland tropical forests that are partly deciduous during the dry season in northern Thailand, in comparison to *L. microphyllum* that is mostly a swamp inhabiting species, but it can live on heavy soils in high rainfall areas. Near its northern limits in southern China *L. flexuosum* is sympatric with *L. microphyllum* and *L. japonicum* (Thunb.) Sw. Although *S. aranea* has been found only in Thailand thus far, this species may be more widely distributed, because the host plant, *L. flexuosum*, occurs widely from Southeast Asia to Australia.

**Mimicry and Morphological Convergence.** The adult and larva exhibit extraordinary morphological modifications whose functions are unknown but may presumably be for defense against predators and/or parasites. The wing pattern of the adult (Figs. 1A and B) resembles legs held in a laterigrade fashion resembling those of the Thomisidae, the crab spider family (J. Miller, personal communication). There have been a few behavioral observations on adult moth species mimicking spider behavior in defense against spider predation (Manu 2003, Rota 2003, Aiello and Becker 2004), but it has not been observed in *S. aranea*. The larvae *S. aranea* have a morphological adaptation of the anal shield that does not occur in any other known stem-boring pyraloid that may provide protection from predation and/or parasitism. The anal shield is modified as a cup-like structure with a margin surrounded by setae (Fig. 4A–C), very similar to that of some beetle larvae (Fig. 4D–F), specifically Amarygmini tenebrionid larvae (Spilman 1969).

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